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Boundary Flow in Laboratory Permeameters Used To Stimulate Recharge by Cyclic Water Spreading[1]

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Abstract. The contribution of boundary flow to the hydraulic conductivity values obtained from laboratory permeameters employed in cyclic flood-dry infiltration studies was evaluated. Hydraulic conductivity in the boundary zone was less than that of the inner matrix for a 2-mm sand. Conversely, the flow rate was greatest in the boundary zone for the finer textured sandy loam soils. The divergence between the hydraulic conductivity of the inner zone and the boundary zone was greatest during the first flooding period. For both matrix zones, the changes in hydraulic conductivity within a flood cycle and with a number of flood cycles, although of different magnitude, tended to be similar and parallel. A laboratory permeameter design is presented to facilitate partitioning the relative contributions of flow in the boundary and inner zones on the hydraulic conductivity values of soils. (Key words: Hydraulic conductivity; ground water recharge; scaling; infiltration)

INTRODUCTION

The laboratory permeameter is a useful tool for obtaining preliminary data on the design and management requirements of proposed water-spreading facilities [*Schiff*, 1964]. The sustained infiltration rate and hydraulic conductivity of materials at the site may be characterized with permeameters under controlled laboratory conditions. In addition, the effect of management procedures such as organic matter amendments and wet-dry cycling on infiltration rates may be conveniently and economically observed in statistically replicated permeameter units.

The scaling laws that govern the development of models for flow through porous mediums were reviewed by *Greenkorn* [1964]. In addition to scaling problems, a physical limitation of the laboratory permeameters is that flow rates along container walls may differ from those within the soil matrix. Consequently, values for infiltration rate and hydraulic conductivity obtained with permeameters may not be representative of actual values in the soil. *Brinkman* [1949] developed a modified form of Darcy's equation which included a term to describe flow through the adjoining empty spaces in a porous medium. According to *Bird et al.* [1960], this term may be used to account for distortion of velocity profiles near containing walls. *McNeal and Reeve* [1964] observed errors in hydraulic conductivity measurements caused by boundary flow when water of varying ionic composition was used in permeameter studies. They presented a permeameter design wherein the error of boundary flow could be minimized in the calculation of hydraulic conductivity values. Quantitative evaluation of wall effects in permeameters for coarse textured materials (16-mm mean diameter) was recently reported by *Dudgeon* [1967].

Usually the hydraulic conductivity of the

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soil material in a permeameter is evaluated during one continuous flood cycle. It is known, however, that the infiltration rate of a soil can be altered appreciably by alternate flood-dry cycles of short duration [*Worcester*, 1967]. Since wetting and drying of soils containing even small amounts of clay can lead to appreciable swelling and shrinking, it appeared important to evaluate the potential contribution of boundary flow under these conditions to hydraulic conductivity values obtained with laboratory permeameters.

METHODS AND MATERIALS

The permeameter design presented here was a modification of that of McNeal and Reeve. The permeameter unit was constructed from plexiglas tubing 7.5 cm I.D. and 30.0 cm long (Figure 1). A plexiglas ring 5.0 cm I.D. by 3.75 cm with a 20° knife edge on top sloping outward was fitted to the bottom plate of the permeameter concentric with the larger cylinder. The function of the inner ring was to partition flow at the discharge end of the permeameter into flow through a core in the center of the soil matrix and flow through an annular zone concentric to the inner core, which included flow at the soil-permeameter interface.

The annular area between the inner ring and the larger cylinder was drained through two 0.5-cm I.D. outlets located 180° apart. The area within the inner ring was drained through a 0.6-cm I.D. outlet. Outlets were fitted with flexible plastic tubing. The elevation of the discharge end of the tubing was adjusted to that of the bottom of the soil in the permeameter to ensure atmospheric pressure at this location. Inlet and overflow tubes were constructed of 0.6-cm I.D. plexiglas tubing. The inlet tube was attached to a reservoir, also equipped with an overflow tube. This reservoir served as a secondary head control device and as a chamber in which the temperature of the water was permitted to equilibrate with the ambient air temperature.

Three materials were chosen for investigation: a graded 2.0-mm blasting sand, Mohave sandy

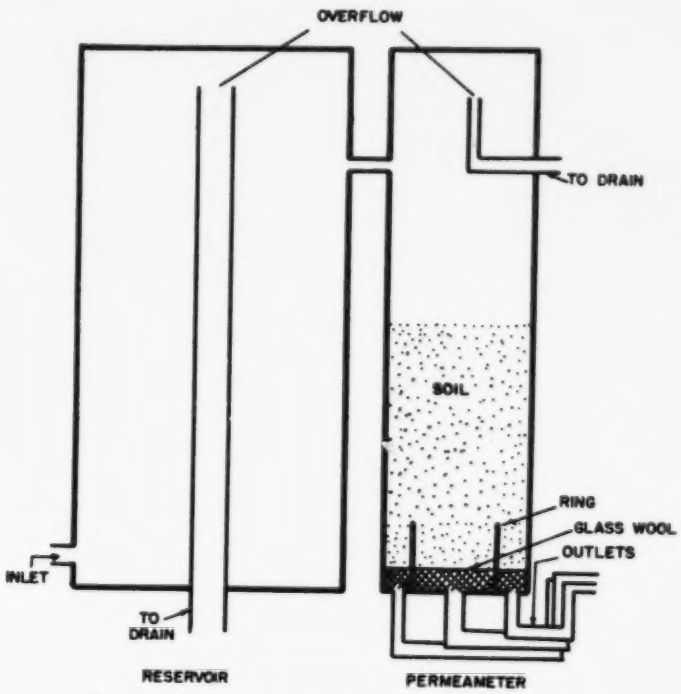

Fig. 1. Design of permeameter and head control devices.

loam subsoil (76.8% sand, 6.9% silt, and 16.3% clay), and Mohave fine sandy loam (66.7% sand, 20.4% silt, and 12.9% clay). The permeameters were filled to a depth of 15.0 cm and packed as uniformly as possible by tamping. Tap water with an electrical conductivity of 0.6 mmhos cm (approximately 390 mg/L total dissolved salts) was used. Since it was desired to simulate field conditions, a bactericide was not added, and the water was not de-aired but was allowed to equilibrate with ambient temperature before application. The permeameters were flooded for approximately 48 hours. Effluent was collected and measured periodically. The columns were drained for 72 hours while air was blown across the surface to enhance drying. During the drying period most of the decrease in soil moisture occurred within the surface 2- to 5-cm of material. After the drying period the moisture content by weight was 1%, 5%, and 6% at 1 cm and 12%, 12%, and 8% at 12 cm in the fine sandy loam, blasting sand, and sandy loam, respectively. Flood-dry cycles were run on duplicate samples of each material. The mean values for hydraulic conductivity were standardized to 20°C to correct for viscosity differences.

Piezometric readings of hydraulic head above the inner ring, inside the inner ring, and inside the annular zone indicated that the ratio of inner to outer ring cross-sectional area and the ring height were adequate to permit full drainage of effluent during flooding. The cross-sectional area of each region was used to calculate the hydraulic conductivity for each matrix zone.

RESULTS AND DISCUSSION

Hydraulic conductivity data for three flooding periods in the 2-mm blasting sand are presented in Figure 2. The hydraulic conductivity curves for the outer zone were consistently lower than those for the inner matrix region, in contrast to the results obtained for the finer materials in this study (see Figures 3 and 4) and from results reported in the literature [*McNeal and Reeve*, 1964]. Apparently air masses entrapped between the permeameter wall and the soil matrix produced a reduction in permeability in this region similar to that observed in capillary tubes by the Jamin effect [*Wyckoff and Botset*, 1936].

The parallelism of conductivity values observed for the outer and inner matrix would be expected, since the outer region comprised 55% of the total infiltration surface. Thus the conductivity of the matrix-permeameter wall boundary was superimposed on that through the outer matrix region.

Hydraulic conductivity curves for five flooding-drying cycles in the Mohave sandy loam are shown in Figure 3. The curves for the inner

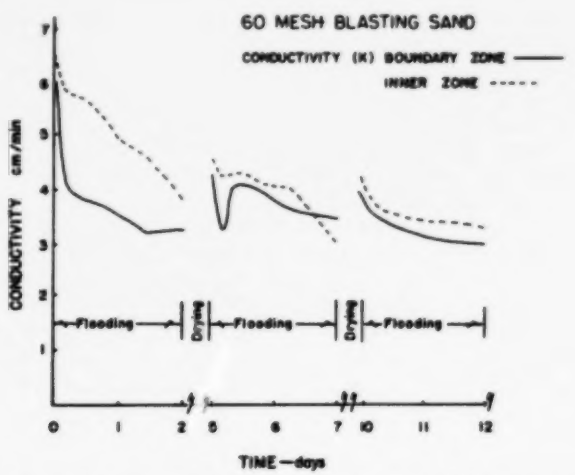

Fig. 2. Comparison of hydraulic conductivity values in the boundary zone and the internal matrix during flood–dry cycles in 60-mesh blasting sand.

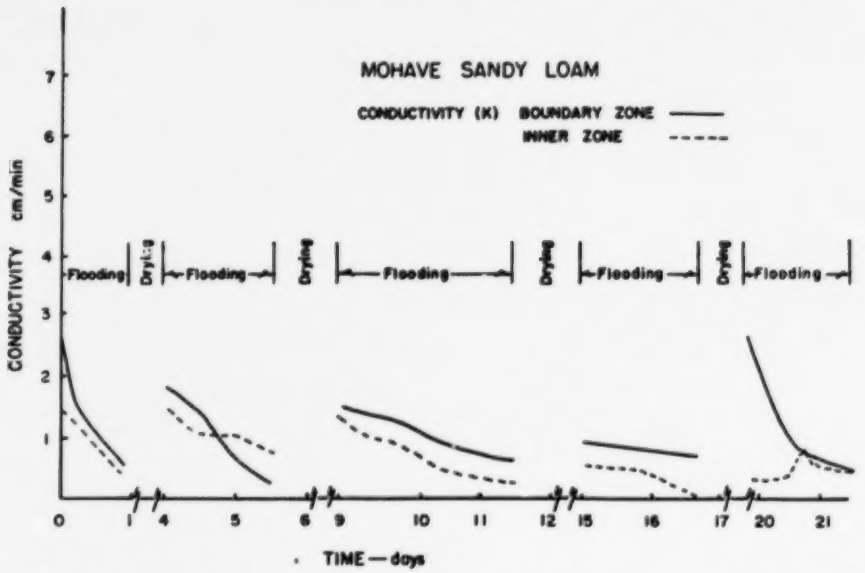

Fig. 3. Comparison of hydraulic conductivity values in the boundary zone and the internal matrix during flood-dry cycles in Mohave sandy loam.

zone were for the most part below the curves for the outer zone, indicating that boundary flow velocities were greater than those within the soil matrix. The two curves were fairly close during the first and second cycles but diverged in the third and subsequent flooding periods, indicating that the contribution of boundary flow to the flow regime in the outer region became of more significance as flow rates were reduced within the soil matrix.

The general shapes of the curves for the inner and outer regions were similar, again indicating the superposition of flow through the matrix on flow along the wall. Reduced flow rates within the soil matrix during successive cycles may have been caused by an increase in air entrapment, coupled with changes in aggregation at the soil surface accompanying 'wet-dry weathering' [*Feng and Browning*, 1946] and/or microbial activity in combination with physical changes [*Gupta and Swartzendruber*, 1962]

In trials using Mohave fine sandy loam, the five hydraulic conductivity curves for the boundary region were consistently higher than those for the inner region (Figure 4). In contrast to the curves for the Mohave sandy loam (Figure 3), the conductivity curves for the inner region of permeameters containing fine sandy loam were considerably lower than the curves for the outer region but tended to converge after the second cycle. The contribution of boundary flow gradually became of less significance. The conductivity curves for both regions increased during the second and third cycle over corresponding curves during the first cycle. Similar trends in conductivity values during cyclic operation of lysimeters were reported by *Bliss and Johnson* [1952] and *Worcester* [1967], who attributed the increase in conductivity to increased porosity resulting from the combined effect of microbial activity and drying on soil structure.

For the three materials used in this study, it was apparent that boundary flow along permeameter walls influenced hydraulic conductivity values obtained in the soil matrix near the wall. Therefore, for critical studies on the effect of various cyclic treatments on the hydraulic conductivity, neglecting boundary flow may introduce significant errors in the interpretation of results. In this case the laboratory permeameter design presented here permits accounting for

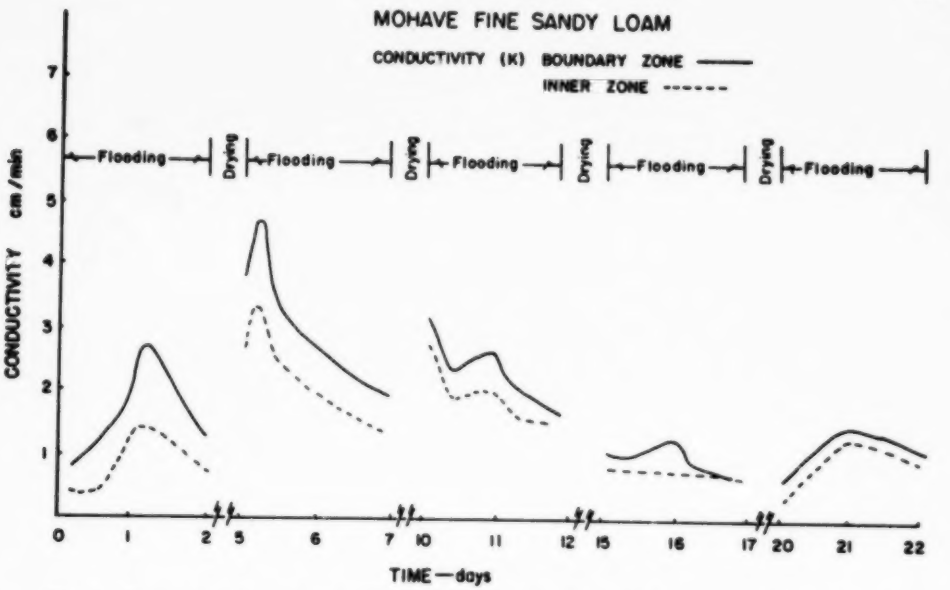

Fig. 4. Comparison of hydraulic conductivity values in the boundary zone and the internal matrix during flood-dry cycles in Mohave fine sandy loam.

the boundary flow. Because of the parallelism of conductivity curves for the inner and outer regions, however, boundary flow may be ignored if only gross trends produced by cyclic treatment are desired.

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